

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED Final Report 1/1/95-5/31/96
----------------------------------	----------------	---

4. TITLE AND SUBTITLE Equipment for Visualization of Large-Scale Fluid Dynamics Calculations	5. FUNDING NUMBERS F 49620-95-1-0100
---	---

6. AUTHOR(S) Paul Fischer      C-W Shu W.S. Don D. Gottlieb	
--	--

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Division of Applied Mathematics Brown University Providence, RI 02912	ORGANIZATION <b>AFOSR-TR-96</b> <b>0542</b>
---	---

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research 110 Duncan Avenue, Suite B 115 Bolling AFB, DC 20332-8080 <span style="float: right; font-size: 1.5em;">nm</span>	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
---	--

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT  <span style="font-size: 2em; font-family: cursive;">unlimited</span>	12b. DISTRIBUTION CODE
--	------------------------

13. ABSTRACT (Maximum 200 words)

see attached.

19961104 066

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
---------------------------------------	--	---	----------------------------

## Final Technical Report for AFOSR Grant # F49620-95-1-0100

### Equipment for Visualization of Large-scale Fluid Dynamics Calculations

Paul Fischer  
Division of Applied Mathematics  
Brown University  
Providence, RI 02912

### Technical Objectives

Grant # F49620-95-1-0100 was a DURIP equipment Grant in support of ongoing research in high-order numerical methods at Brown University. The equipment purchased included a 1 Gbyte SGI Onyx, and two smaller SGI Indigo II's for Professors Gottlieb and Don, as well as ATM switching network for improved data transfer within the Center for Fluid Mechanics computing center which supports our scientific computing group. The SGI Onyx is being used by many faculty and students in the scientific computing group and Center for Fluid Mechanics in applied mathematics.

The principal aims of providing the Onyx as large memory compute server were to provide graphics capability for the analysis of large two- and three-dimensional data sets arising in computational fluid dynamics simulations carried out at remote supercomputing sites, and to provide a local *serial* platform with sufficient RAM to permit rapid development of iterative solvers which are to ultimately be implemented on remote parallel supercomputers. The ATM network and smaller SGI's facilitates data transfer between the Onyx graphics/compute server and individual workstations as well as improved data throughput to and from the diskfarms.

### Equipment Purchased

Please see attached.

### Technical Accomplishments

#### *Flow Visualization*

We primarily use flow visualization as a tool rather than undertake development of visualization software. One of the SGI Indigo II's is used by Prof. W.S. Don to study shock induced vortex formation in hydrogen-air mixtures for scramjet combustors. The Indigo II has greatly reduced rendering times for computational results of his  $512 \times 512$  spectral calculations, allowing him to view more frames of data and consequently pinpoint some of the critical phenomena in flame front enhancement. Visualization of this type is a powerful

tool to aid both numerical and experimental researchers in this project in developing a better understanding of combustion dynamics.

Visualization on the SGI Onyx is currently being used to analyze heat transfer in three-dimensional models of high-performance heat exchangers by Prof. Fischer, and in the study of turbulence by researchers in the Center for Fluid Mechanics group with whom we share systems and network support. Prof. Don has recently undertaken three-dimensional simulations which will necessitate the use of the Onyx as a graphics engine due to memory requirements.

### *Iterative Algorithm Development*

The acquisition of the SGI Onyx has been instrumental in the recent development of an overlapping Schwarz iterative scheme for spectral element solution of the Navier-Stokes equations and Grant # F49620-95-1-0100 has been cited for computational support of this project in [1]. This new iterative algorithm yields a five-fold reduction in CPU time for current production runs and is inherently parallel. The resultant code is currently being used by NASA contractors in the study of Helmholtz resonators used for aircraft noise suppression.

Because of the large memory capacity of the Onyx, we were able to test and develop serial versions the algorithm in house on fluid dynamics simulations of production size (up to 500,000 gridpoints). Consequently, we could study the performance of the algorithm under severe test conditions without the unnecessary burden of implementing a fully functional parallel version or of having to repeatedly ship source code to a remote supercomputing site. Without the Onyx, we would have had to base the development work on the results of much smaller test computations which frequently do not reveal the weaknesses of iterative methods, or undertake the development and simultaneous debugging of parallel code which would have greatly slowed the process. It is unlikely that the new algorithm would have reached its current state of refinement if we had attempted the development remotely on a parallel computer as the turn around time at such sites is simply too slow for efficient development work.

We are presently extending the scheme to three-dimensional computations and to parallel. The three-dimensional work is being carried out on the SGI Onyx, while the parallel development is being done on the Intel Paragon at WPAFB and the Intel Delta at Caltech.

## **Publications**

This is a one-year equipment grant which primarily addresses infrastructure improvements for scientific computing in the Applied Mathematics Division at Brown and as such does not support individual researchers. However, it was instrumental in facilitating the work detailed in the publication below and is cited as such.

[1] P. Fischer, "An overlapping Schwarz method for spectral element solution of the incompressible Navier-Stokes equations," submitted to the *J. of Comp. Phys.* (1996)

21-Oct-96

AFOSR/DURIP EXPENSES - F49620-95-1-0100

1

VENDOR NAME	DESC. OF EQUIPMENT	COST TO GRANT
FORE SYSTEMS	ATM INTERFACES	\$4,900.35
SILICON GRAPHICS	POWER ONYX	\$261,755.00
ANDATACO	8 X 4.2 GBYTE SUBSYSTEM	\$17,583.42
SILICON GRAPHICS	75' CABLE & KEYBOARD FOR ONYX	\$82.90
ANDATACO	128 MBYTE SIMMS	\$9026.39
CISCO SYSTEMS	LIGHTSTREAM 1010 ATM SWITCH	\$21,431.94
		=====
	TOTAL	\$314,800.00